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USAAVLABS TECHNICAL NOTE 2

MEASUREMENT OF DAMPING COEFFICIENTS AND DYNAMIC MODULUS OF FIBER COMPOSITES

By

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E. B. Paxson

R. L. Rodgers

February 1970

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

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ABSTRACT

The development of new materials, such as fiber-reinforced plastics (FRP), with attendant claims of high damping as compared to metals, has led to an increased interest in the damping coefficients and dynamic modulus of these materials. No theoretical methods are available to describe the mechanism of damping in FRP. The experimental techniques developed to measure the material damping of FRP were exponential decay of a vibrating beam (free-free mode) and forced vibration of a double cantilever beam.

Al 2024-T4 was chosen for initial experiments to verify measurement technique. By using Zener's anelastic theory of damping for metals, theoretical damping values were calculated and compared with experimental damping values. Good agreement was achieved. The experimental techniques were then applied to fiberglass-reinforced composites and boron-reinforced composites.

It was found that damping values for the unidirectional fiberglass and boron composite specimens had approximately the same magnitude as those for the aluminum specimens. However, variations in fiber orientation produced a significant increase in damping coefficients. Also, the introduction of air damping produced an increase in the observed value of material damping. The parameters of stress level and frequency were controlled, and the effect of these parameters on the values of material damping and dynamic modulus was observed and recorded.

FOREWORD

The authors wish to acknowledge the contributions of Mr. E. McIlwean and Mr. C. Oaten, both of U. S. Army Aviation Materiel Laboratories, who prepared the test specimens and assisted in the conduct of experiments and the recording of test data.

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INTRODUCTION

The development of new materials, such as fiber-reinforced plastics (FRP), with attendant claims of high damping as compared to metals, has led to an increased interest in the damping coefficients and dynamic modulus of these materials and to subsequent investigation. This work was supported by in-house composite material studies. Experimental investigation revealed that the material damping values for composites could be greater or less than damping values for metals, dependent upon composite fiber orientation.

No theoretical methods were available to describe the mechanism of damping in fiber composites. Furthermore, detailed measuring techniques and related damping coefficients for composite materials were not available.

In the areas of vibrational fatigue and aerodynamic stability, the actual values of material damping are important design considerations. Accordingly, with the advent of composite materials replacing existing metal aircraft components and structures, the actual values of damping coefficients for composite material reported herein are important preliminary and conceptual design parameters.

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TESTING TECHNIQUES

Of several methods of investigation that were considered, forced vibration of a double cantilever beam and free-free vibration of a beam specimen were chosen for initial studies. Steel and aluminum were chosen as the materials to be investigated, because their parameters are well documented and thus provided a source from which theoretical damping coefficients could be calculated and compared with experimental values.

Various gripping techniques were investigated; a review of related work[1] indicated that some type of raised center section provided an optimum grip technique for forced vibration testing. Epoxy "shoulders" molded to the center of the beam were chosen as a means for converting a flat reed specimen into a double cantilever beam (see Figure 1). The test setup for forced vibration of double cantilever beams is shown in Figure 2.

To provide a basis for comparison of experimental data, the exponential decay of a free-free beam with the same beam dimensions used in the forced-vibration experiments was measured. The free-free method of testing offered the most promise in minimizing the effect of grips/support (see Figure 3). All testing was conducted in a vacuum environment to avoid the introduction of air damping.

The experimental values of damping coefficients obtained for aluminum 2024-T4 were closely aligned to calculated theoretical values. These values are compared in Figure 4. The theoretical damping coefficients for aluminum were calculated using Zener's anelastic theory of metal.[2] When the Zener equation is used, handbook values for the physical constants for specific heat and thermal conductivity should not be used; the constants should be measured from a representative sample of the material under investigation. Failure to follow this procedure could result in a significant shift in the damping-coefficient-versus-frequency curve.

The experimental values of damping coefficients were obtained by exciting the test beam and recording the resultant transient wave. A more detailed explanation of the measurement techniques, associated formulas, and equipment setup is available in Reference 3.

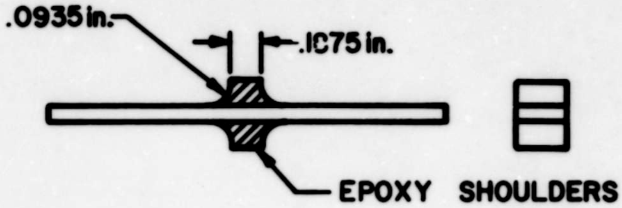

Figure 1. Forced Vibration, FRP Test Specimen Geometry.

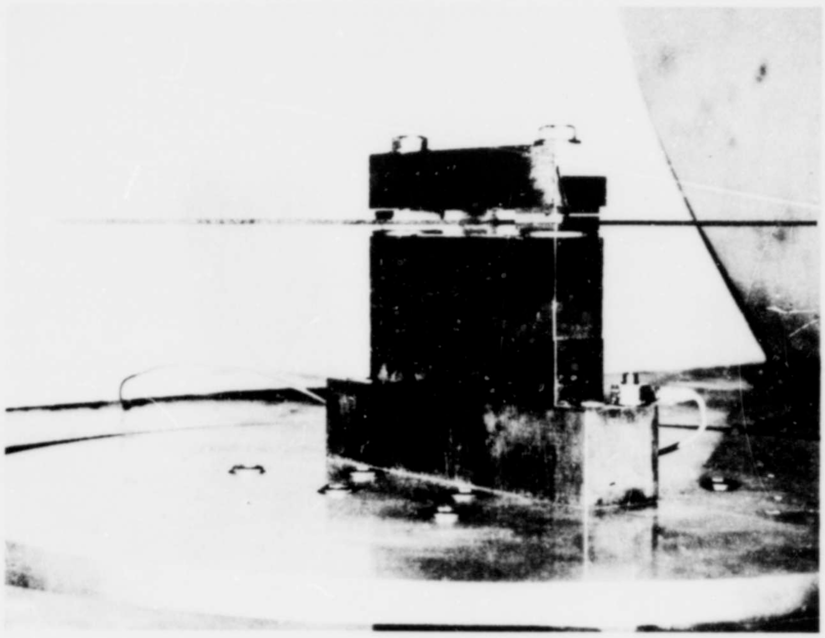

Figure 2. Double Cantilever FRP Beam Mounted on Electrodynamic Shaker Head.

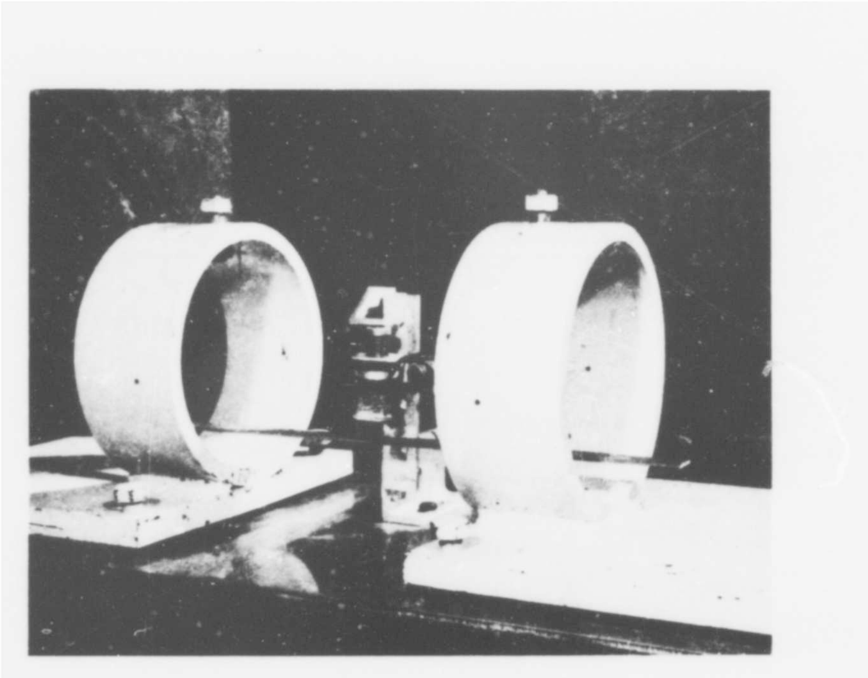

Figure 3. Free-Free Test Apparatus.

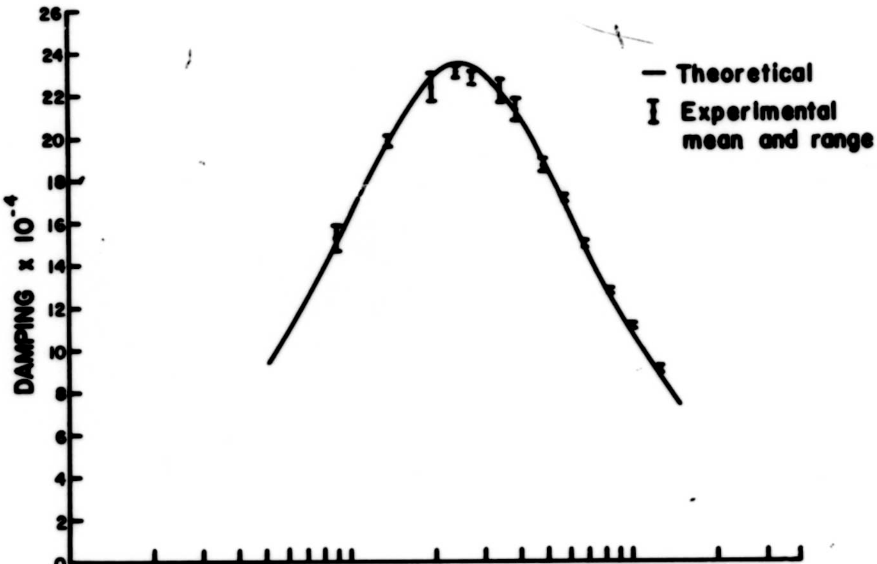

Figure 4. Damping Versus Frequency for 2024-T4 Aluminum; Theoretical and Experimental.

RESULTS

FIBERGLASS-REINFORCED COMPOSITES

The experimental techniques of free-free and forced vibration were applied to fiberglass-reinforced composites (3M 1009-26S) with unidirectional (0°) and 0°-90° fiber orientations.

Damping Coefficients

The forced vibration damping values were somewhat higher than free-free damping values for the same fiber orientation. Even with the optimum grip design, a portion of the beam energy was fed into the supports. The experimental values of damping coefficients for both free-free and forced vibration techniques for composites with fibers oriented at 0° and 0°-90° are presented in Table I.

The attendant high damping for composites as compared to metal was not achieved with unidirectional composites. However, higher damping values were obtained with the introduction of cross-ply fibers within the composites (see Figure 5).

Dynamic Modulus

The values of dynamic modulus obtained from free-free vibration test data as compared to those obtained from forced vibration data presented marked contrast (see Table II). In each instance (0° and 0°-90° composites), the values of dynamic modulus were higher for the free-free test method. The free-free dynamic modulus values were in good agreement with manufacturers' published values for modulus in bending. Sufficient testing and analysis have not been conducted to establish the conditions that contribute to this situation of lower modulus values for forced vibration testing; however, the formula used to calculate the dynamic modulus was for idealized vibration conditions. It did not take into account the possible presence of a torsional motion or significant higher mode vibrations during forced vibration testing. The values of dynamic modulus for both free-free and forced vibration testing of composites were calculated using the following relationship:

$$E = \frac{f_n^2 \, l^4 \, PA}{C^2 \, I} \qquad \text{(Reference 4)}$$

where E = dynamic modulus

f_n = natural frequency

l = beam length

P = material density

A = beam cross-sectional area

I = beam moment of inertia

C = constant (3.56 for free-free vibration; 0.56 for forced vibration)

Damping Versus Stress Level

Use of the forced vibration test technique made it possible to control beam vibrational amplitude at a desired level and frequency. The cantilever beam root stress was adjusted to a level of 10,000 psi for the unidirectional specimens and 2,000 psi for the 0°-90° specimens, at their respective natural frequencies (peak amplitudes). Measured material damping coefficients were independent of stress level below 30,000 psi for 0° and 15,000 psi for 0°-90°. However, above these stress limits, the resonance curves were unsymmetrical and the corresponding calculated damping values were not meaningful. Another indication of nonlinear response was the inability to maintain a constant vibration amplitude at a fixed frequency. With the root stress of the beam above the 30,000- and 15,000-psi levels, the beam tip amplitude decreased slowly from its peak value. A frequency search revealed that the peak amplitude occurred (momentarily) at a lower resonance frequency.

BORON-REINFORCED COMPOSITES

In the next series of damping experiments, boron-reinforced composite materials were used. Laminates consisted of unidirectional (0°), $\pm 45^\circ$, and 90° oriented fibers with NARMCO 5505 epoxy resin matrix.

Damping Coefficients

Both the free-free and the forced vibration techniques were used to determine material damping. Figure 6 illustrates two important characteristics of boron composite damping values. First, the values

of damping for 90° and ±45° boron composites are significantly higher than those for unidirectional (0°) composites. Second, the difference in damping coefficients between ±45° and 90° composites remains somewhat constant up to a frequency of 100-125 cps; above this frequency, the 90° boron composite displays a marked increase to a damping level closely identified with ±45° composite damping values. The damping coefficient values for the forced vibration test technique were higher than respective free-free vibration values. Table III provides a direct comparison of free-free and forced vibration damping values.

Air Damping

The introduction of air damping produced an increase in the observed values of material damping. However, for the thin, reed-type test specimen used in these experiments, the presence of air was detectable but not significant for ±45° and 90° composites. The intrinsic material damping coefficients for ±45° and 90° composites were substantially greater than the damping caused by the introduction of air. The material damping coefficients for unidirectional composites were comparable to the damping caused by the introduction of air. Accordingly, the material damping of unidirectional composites must be measured in vacuum. However, this vacuum environment is not mandatory when testing ±45° and 90° composites.

The experimental values of damping for each of the three fiber orientations, with respect to altitude simulation from 0 to 100,000 feet, are given in Table IV.

High-frequency free-free vibration testing was considerably more difficult to perform than low-frequency vibration testing. The short length required for these test specimens produced swaying or nonflexure beam motion in many instances instead of sinusoidal vibration and exponential decay. Accordingly, the present free-free support and excitation fixtures are not suitable for beams of higher frequency (above 300 cps). One method of obtaining higher frequencies of vibration, while still maintaining the desirability of the free-free support method, is to excite the test beams at their nodal points electromechanically.

Dynamic Modulus

The values of dynamic modulus obtained for boron composites using free-free and forced vibration test techniques were more consistent than the fiberglass test values. However, some irregularities were present; namely, the dynamic modulus values for ±45° boron material were higher than expected or measured static modulus values. These

observed dynamic modulus values were present for both free-free and forced vibration test techniques. Sufficient testing has not been conducted to establish the conditions which contribute to this situation. The free-edge effect of the $\pm 45^{\circ}$ fibers and/or the increased resistance to shear loading at high vibrational amplitudes may be contributors. However, the values of dynamic modulus for unidirectional and 90° boron composites were more consistent and in line with static modulus values. The experimental values of dynamic modulus for both free-free and forced vibration test conditions are presented in Table V.

Damping Versus Stress Level

Beam vibrational amplitude was controlled during forced vibration testing. Accordingly, the peak root stress of the cantilever beam specimens with unidirectional (0°) fiber orientation was adjusted to a level of 14,000 psi. For the fiber orientations of $\pm 45^{\circ}$ and 90°, the damping coefficients were measured at stress levels of 500 psi and 1,000 psi, respectively. Stress limits of 40,000 psi, 2,000 psi, and 3,000 psi ror 0°, $\pm 45^{\circ}$, and 90° composites, respectively, did not affect the measured values of material damping coefficients. However, above these limits, the resonance curves were unsymmetrical and the corresponding calculated damping values were not meaningful.

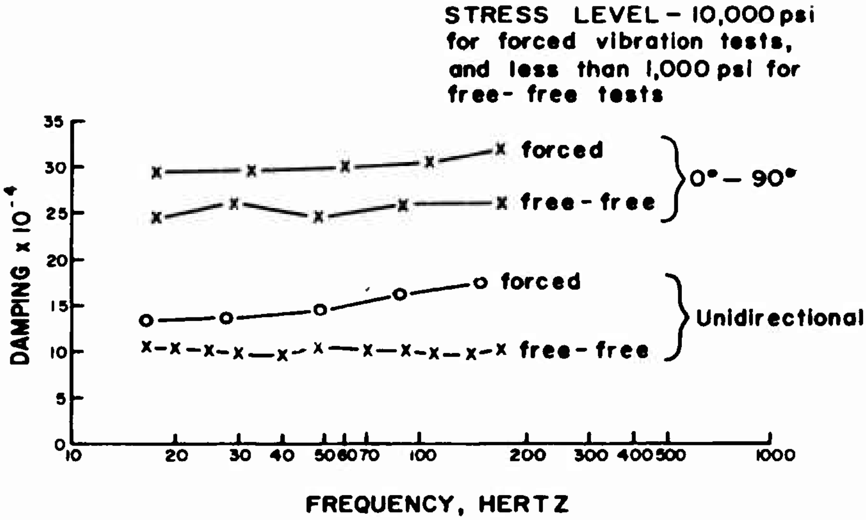

Figure 5. Damping Versus Frequency for Fiberglass (1009-26S), Unidirectional and 0^o-90^o Layup; Forced Vibration and Free-Free Test Procedures.

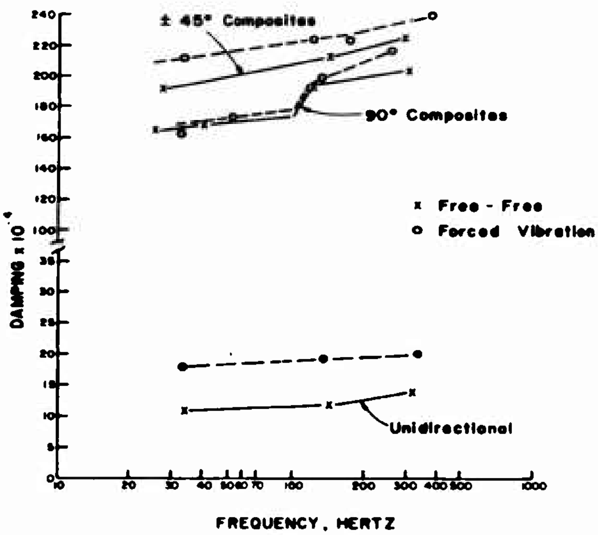

Figure 6. Damping Versus Frequency for Boron (NARMCO 5505), Unidirectional, 90^o, and $\pm 45^o$; Forced Vibration and Free-Free Test Procedures.

TABLE I. DAMPING COEFFICIENTS OF FIBERGLASS COMPOSITES, FREE-FREE AND FORCED VIBRATION TECHNIQUES, PRESSURE .2mm Hg, TEMPERATURE 72°-80°F

Freq (Hz)	Free-Free Vibration Damping x 10^{-4}	Fiber Angle (deg)	Freq (Hz)	Forced Vibration Damping x 10^{-4}
16.62	10.60	0	16.29	13.20
24.92	10.09	0		
29.87	10.04	0	28.87	13.65
40.00	9.94	0		
50.00	10.87	0	51.38	14.50
70.00	10.20	0		
90.00	10.03	0	88.82	17.30
110.00	10.05	0		
140.00	9.97	0	146.04	18.10
170.00	10.32	0		
17.70	23.93	0-90	18.18	28.90
28.63	26.10	0-90	32.90	28.80
50.35	24.46	0-90	56.93	29.90
90.00	26.30	0-90	104.16	30.85
158.00	26.36	0-90	168.63	30.70

TABLE II. DYNAMIC MODULUS OF FIBERGLASS COMPOSITES, FREE-FREE AND FORCED VIBRATION TECHNIQUES, PRESSURE .2mm Hg, TEMPERATURE 72°-80°F

Freq (Hz)	Free-Free Vibration Modulus x 10^6 psi	Fiber Angle (deg)	Freq (Hz)	Forced Vibration Modulus x 10^6 psi
16.62	7.80	0	16.29	6.39
24.92	7.76	0		
29.87	7.74	0	28.87	6.83
40.00	7.81	0		
50.00	7.81	0	51.38	7.20
70.00	7.79	0		
90.00	7.81	0	88.82	6.76
110.00	7.82	0		
140.00	7.81	0	146.04	6.80
170.00	7.79	0		
17.70	5.30	0-90	18.18	5.15
28.63	5.26	0-90	32.90	5.02
50.35	5.31	0-90	56.93	4.63
90.00	5.17	0-90	104.16	4.84
158.00	5.24	0-90	168.63	4.72

TABLE III. DAMPING COEFFICIENTS OF BORON COMPOSITES, FREE-FREE AND FORCED VIBRATION TECHNIQUES, PRESSURE .2mm Hg, TEMPERATURE 70°-90°F

Freq (Hz)	Free-Free Vibration Damping x 10^{-4}	Fiber Angle (deg)	Freq (Hz)	Forced Vibration Damping x 10^{-4}
34.20	11.66	0	34.42	17.42
140.00	12.34	0	135.45	18.90
300.00	13.53	0	304.16	19.33
28.33	188.30	±45	32.10	208.00
		±45	106.60	220.10
144.50	213.60	±45	155.00	214.00
294.12	220.61	±45	313.15	239.30
25.00	162.51	90	29.05	154.50
39.20	166.79	90	52.60	167.50
123.30	193.60	90	134.20	195.00
278.00	199.47	90	262.92	212.60

TABLE IV. DAMPING COEFFICIENTS OF BORON COMPOSITES, VARIABLE AIR PRESSURE, FREE-FREE VIBRATION TECHNIQUE

Frequency (Hz)	Altitude (ft)	Damping x 10^{-4}	Fiber Angle (deg)
34.2	0	14.99	0
	10,000	14.20	0
	50,000	12.53	0
	100,000	11.66	0
140.00	0	14.91	0
	10,000	14.43	0
	50,000	12.88	0
	100,000	12.34	0
300.00	0	14.46	0
	100,000	13.53	0
28.33	0	196.00	±45
	10,000	195.70	±45
	50,000	191.50	±45
	100,000	188.30	±45
144.50	0	221.90	±45
	10,000	219.70	±45
	50,000	216.50	±45
	100,000	213.60	±45
294.12	0	224.50	±45
	100,000	220.60	±45
25.00	0	168.50	90
	10,000	168.60	90
	50,000	164.40	90
	100,000	162.50	90

TABLE IV - Continued			
Frequency (Hz)	Altitude (ft)	Damping x 10^{-4}	Fiber Angle (deg)
39.20	0	169.20	90
	10,000	168.20	90
	50,000	168.70	90
	100,000	166.80	90
123.30	0	194.60	90
	10,000	195.00	90
	50,000	194.20	90
	100,000	193.60	90
278.00	0	216.10	90
	100,000	199.50	90

TABLE V. DYNAMIC MODULUS OF BORON COMPOSITES, FREE-FREE AND FORCED VIBRATION TECHNIQUES, PRESSURE .2mm Hg, TEMPERATURE 70°-90°F

Freq (Hz)	Free-Free Vibration Modulus x 10^6 psi	Fiber Angle (deg)	Freq (Hz)	Forced Vibration Modulus x 10^6 psi
34.20	24.92	0	34.42	26.93
140.00	26.10	0	135.45	25.16
300.00	26.79	0	304.16	23.81
28.33	2.93	±45	32.10	3.42
		±45	106.60	3.62
144.50	3.12	±45	155.00	3.75
294.12	3.27	±45	313.15	3.74
25.00	2.66	90	29.05	2.87
39.20	2.69	90	52.60	2.77
123.30	2.66	90	134.20	2.77
278.88	2.65	90	262.92	2.69

Static Modulus:

0° - 29.4×10^6 psi
$\pm 45^{\circ}$ - 3.0×10^6 psi
90° - 2.9×10^6 psi

CONCLUSIONS

It is concluded that:

1. Material damping values for fiber-reinforced plastic composites having $\pm 45^\circ$ and 90° fiber orientations are from 10 to 20 times higher than those for unidirectional composites, aluminum, and steel. See Figure 7 for a direct comparison of aluminum- and fiber-reinforced plastic composites.

2. Measured material damping values are independent of stress level for up to 20 percent of the material's ultimate strength.

3. Air damping has a measurable effect on the material damping coefficients of composites. The values of air damping are nonlinear, and their main influence occurs at low-frequency (high-amplitude) vibration.

4. Dynamic modulus of composites is dependent upon test technique, stress level, and frequency.

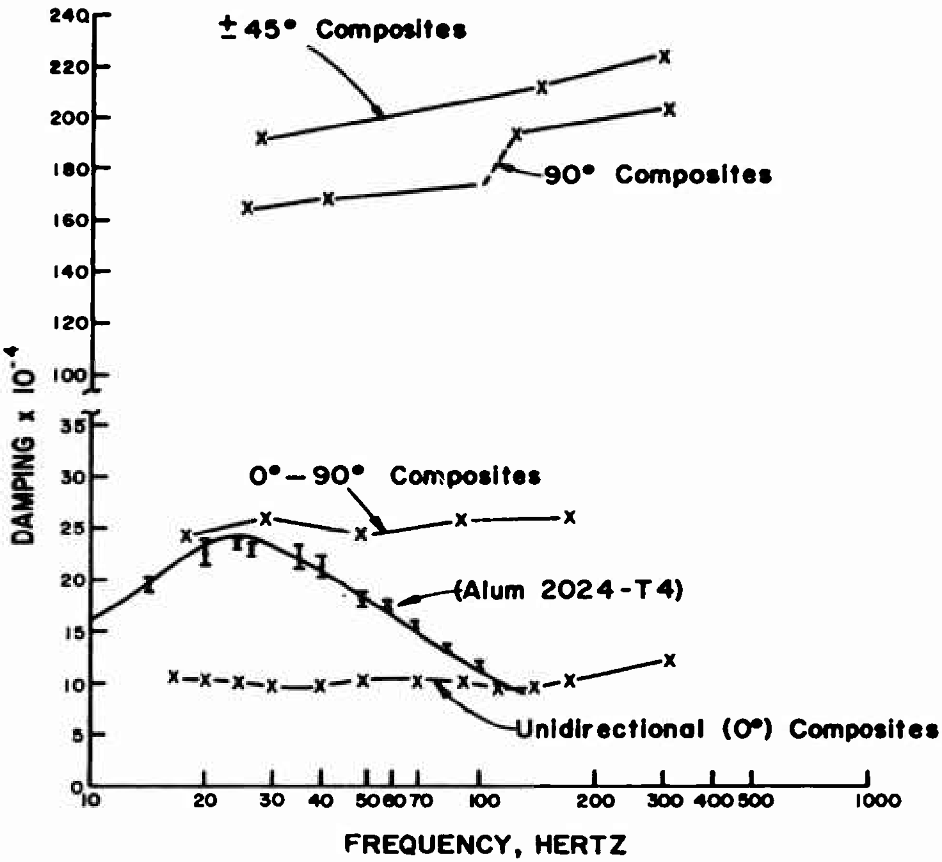

Figure 7. Damping Versus Frequency for Aluminum and Fiber-Reinforced Composites.

LITERATURE CITED

1. Granick, Neal, and Stern, Jesse E., MATERIAL DAMPING OF ALUMINUM BY A RESONANT-DWELL TECHNIQUE, NASA TN D-2893, Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia, 1965.

2. Zener, Clarence, ELASTICITY AND ANELASTICITY OF METALS, Fifth Impression, Chicago, The University of Chicago Press, 1965.

3. Gustafson, A. J., Paxson, E. B., and Mazza, L. T., MEASUREMENT OF DAMPING IN FIBER REINFORCED PLASTICS, Army Science Conference Proceedings, June 1968, AD 837123.

4. Macduff, John N., and Curreri, J. R., VIBRATION CONTROL, McGraw-Hill Book Co., Inc., New York, 1958.

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13. ABSTRACT

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The experimental techniques developed to measure the material damping of FRP were exponential decay of a vibrating beam (free-free mode) and forced vibration of a double cantilever beam.
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It was found that damping values for the unidirectional fiberglass and boron composite specimens had approximately the same magnitude as those for the aluminum specimens. However, variations in fiber orientation produced a significant increase in damping coefficients. Also, the introduction of air damping produced an increase in the observed value of material damping. The parameters of stress level and frequency were controlled, and the effect of these parameters on the values of material damping and dynamic modulus was observed and recorded.

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